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STIMULUS DETERMINANTS OF DYNAMIC VISUAL ACUITY

I. Background and Exploratory Data

James E. Goodson and Tommy R. Morrison

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
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The measurement approach represented by tests of dynamic visual acuity (DVA) appears to offer unique potential for assessing visual capabilities which are required in the performance of naval aviation missions, and for investigating the nature of these visual capabilities. The DVA literature reports significant variations in measures of linearity, magnitude, and continuity of the DVA function. Clarification of the quantitative characteristics of the DVA function is required if measures of this function are to be applied to the assessment and prediction of individual capabilities for visual performance, and if the understanding of this function is to influence task design.

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Approved by

Ashton Graybiel, M.D.
Assistant for Scientific Programs

Released by

Commander W. M. Houk, MC, USN
Commanding Officer

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Naval Aerospace Medical Research Laboratory
Naval Air Station
Pensacola, Florida 32508

SUMMARY PAGE

THE PROBLEM

The measurement approach represented by tests of dynamic visual acuity (DVA) appears to offer unique potential for assessing visual capabilities which are required in the performance of naval aviation missions, and for investigating the nature of these visual capabilities. The DVA literature reports significant variations in measures of linearity, magnitude, and continuity of the DVA function. Clarification of the quantitative characteristics of the DVA function is required if measures of this function are to be applied to the assessment and prediction of individual capabilities for visual performance, and if the understanding of this function is to influence task design.

FINDINGS

Selected areas in the DVA literature are summarized. Descriptive data are reported from three exploratory experiments regarding individual differences and the effects of contrast, luminance, and target surround upon DVA performance. Subjects, whose static visual acuities were better than 20/20, exhibited large individual differences in their abilities to recognize targets moving at 20°/sec and in the rates at which their acuities were degraded for higher target velocities. Initial data suggests that the configuration of the target surround affects DVA performance in a manner not previously observed.

Tommy R. Morrison's present address is Human Factors Engineering Division, Aircraft & Crew Systems Technology Directorate, Naval Air Development Center, Warminster, Pennsylvania 18974.

INTRODUCTION

The measurement of dynamic visual acuity (DVA) has received enthusiastic, if sporadic, attention during the past 30 years for its potential in visual screening and in the investigation of dynamic characteristics of visual performance. During that period, some 73 authors have generated 81 reports on the subject. However, apart from the pioneering work of Ludvigh and Miller, and the subsequent applications by Burg and his coworkers, there has been little in the way of a sustained, programmatic effort to refine the measurement methodology or to understand what is being measured by tests of DVA. This literature reports a large range of levels and variabilities in DVA performance among subjects and within subjects, and a considerable variety in apparatus and methodology for investigating DVA. While the several findings upon which various laboratories agree gain credence by virtue of their diverse sources, the diversity of methods among laboratories leaves little basis for reconciling disparate results.

The purposes of this paper are to inagurate a program of studies intended to define characteristics of the DVA stimulus which contibute to variations in performance and to investigate characteristics of DVA performance which are predictive of practical visual capabilities. This paper will summarize selected areas of clarity and confusion in the DVA literature, and will present initial, exploratory data regarding individual differences and the effects of contrast, luminance, and target surround upon DVA performance.

BACKGROUND

DEFINITION

Dynamic visual acuity (DVA) is a measure of the ability to recognize moving targets during voluntary ocular pursuit. The DVA task requires the observer to detect a target as it traverses the field of view, visually acquire it by one or more successions of saccadic and smooth pursuit eye movements, and resolve some critical detail contained within it, all within a relatively brief exposure time. Reviews of the DVA literature have been reported by Miller and Ludvigh (1) and by Morrison (2). There is general agreement that acuity for a moving target decreases as a function of the target's angular velocity with respect to the observer. This result has been obtained for target movement in a horizontal direction (3, 4), a vertical direction (5, 6), and in a circular path on a plane tangent to the observer's line of sight (7, 8). Similar results are obtained when the observer moves with respect to a stationary target; for example, on a rotating platform (6) or in an airplane (9).

UTILITY

DVA has several characteristics which recommend its inclusion for purposes of visual assessment. Its potential value in clinical assessment is indicated by the apparent requirements for integrity of central and peripheral visual functions and for coordination between visual and oculomotor mechanisms. The content validity of DVA for assessing job performance capabilities

is readily apparent for tasks requiring the recognition of targets moving at angular velocities similar to those tested, and is defensible for a large class of task environments which require the rapid scan and acquisition of visual stimuli.

The literature provides little information regarding concurrent or predictive validities of any vision test with respect to measures of job performance. However, the few validation studies which have included DVA indicate this measure to be among the most valuable for assessing practical visual capabilities. DeKlerk et al. (10) reported DVA to correlate higher than static visual acuity with inflight measures of instrument, formation, and night flying performance. Burg (11, 12) investigated the relationships between a battery of seven vision tests (including DVA, static acuity, visual field, and lateral phorias) and automative driving records. He concluded that DVA demonstrated the strongest and most consistent relationship to automotive driving record of all the vision variables studied. Henderson and Burg (13) obtained significant correlations between DVA and records of accident involvement among truck and bus drivers. These results are remarkable in view of the coarseness of the criterion measures, the large within-subject variability on DVA tests, and the lack of refinement, thus far, in methods for assessing DVA.

CORROBORATED FINDINGS

Although the details of the DVA function are not well understood, the findings that DVA performance deteriorates with increasing target angular velocities is a robust finding, and is generally corroborated across laboratories. Further, it is agreed that DVA is critically dependent upon exposure duration (14–17), that performance is enhanced by increased target contrast (18, 19), that DVA continues to improve with increasing luminance well above the levels for which static acuity has reached an asympote (6, 7, 20), that males score slightly better than females on DVA tests (21, 22, 23), and that DVA performance declines more severely with age than does static visual acutiy (21, 24). The relationship between DVA and static acuity is not entirely clear. It appears that there are large individual differences in DVA among subjects whose static visual acuities are similar (4, 25), and that any correlation between the two is increased when using lower DVA target speeds, binocular viewing conditions, longer exposure times, and free head movement (10, 21–23).

RELIABILITY

The reliabilities of DVA tests appear to depend upon characteristics of apparatus and/or procedure which have not yet been defined. Burg and Hulbert (22) used a rotating projector to present checkerboard targets on a circular screen at speeds of 0, 60, 90, 120, and 150°/sec. When the observer was allowed free head movement, the test-retest reliabilities of the respective acuity measures were 0.53, 0.68, 0.60, 0.58, and 0.43. However, when the head was fixed, test-retest reliabilities were reduced, and did not attain statistical significance. Ludvigh and Miller's (25) subjects viewed a Landolt ring target through a rotating mirror (head fixed). For a target speed of 110°/sec, and 400 msec exposure time, they obtained an estimate of reliability

by the split-half method of 0.99. Using target speeds of 20 and 110°/sec, they computed the test-retest reliability of their DVA index ("b") to be 0.87. Current knowledge does not offer an a priori basis for predicting that one of these methods would produce more reliable measures than the other.

CAUSE OF DEGRADATION

Ludvigh (26) reasoned that the primary cause of degradation in acuity for moving targets is inaccuracy of oculomotor control. This inaccuracy may result in position error, velocity error, or higher order derivatives thereof. Ludvigh and Miller (4) compared Ludvigh's measures of extrafoveal static acuity (27) with his measures of DVA (7) and concluded that the extrafoveal position of the image during the pursuit of DVA targets is probably a negligible factor in the degradation of acuity for moving targets. Ludvigh (7) and Ludvigh and Miller (4) argued effectively that the degradation in acuity for moving targets is due primarily to a mismatch between eye pursuit velocity and target velocity. Several investigators have sought to observe any relationship between oculomotor performance and DVA by recording eye movements during DVA performance (17, 19, 28–32). Although these studies have revealed interesting statistical properties of the relationship between eye movements and target velocity, they have not identified successful versus unsuccesful DVA trials on the basis of eye movement records. This is perhaps due to the confounding of position error with velocity error, and to the apparent tolerance of the visual system for moderate amounts of both.

Apparently, the visual mechanisms which recognize acuity targets have a high tolerance for retinal image motion at low velocities and some tolerance for higher velocities. Westheimer and McKee (33), using foveal presentations lasting 0.1 and 0.2 sec, demonstrated that resolution thresholds for both Landolt rings and vernier targets are unaffected by horizontal or vertical retinal image velocities up to 2.5°/sec. Murphy (34) reported contrast thresholds for a sine wave grating (5.14 cycles/degree) to remain unchanged with retinal slippage up to 1.3°/sec, regardless of whether the relative motion was produced by the eye tracking a fixation target across the grating or by movement of the grating with respect to a stationary fixation target. Barmack (29) used square wave grating targets to test DVA while recording eye movements. With 400 msec exposure time, his subjects performed above chance level for target velocities of 60 and 140°/sec while under instructions to make no eye movements. They performed equally well with and without pursuit eye movements for the 140°/sec condition. Explanations for such tolerances of image motion on the retina are not yet available, nor is the extent of their effect upon DVA performance understood.

QUANTITATIVE DESCRIPTION

The major attempt at a quantitative description of the DVA function is represented in the early work of Ludvigh and Miller (3, 4). Using group data, they determined the best empirical fit to a polynominal of the form $y = a + bx^n$, where y = target size in minutes of arc, x = target angular velocity in degrees per second, n is a positive integer which was

determined empirically to equal 3, and a and b are parameters to be determined by curve fitting to data, using the method of moments. This statement of the DVA function in terms of two subject parameters appears to offer advantage over the alternative method of specifying individual acuity measures for each of a series of target velocities. The "a" parameter provides an estimate of acuity for stationary targets, and "b" provides an index of the rate of degradation of acuity with increasing target angular velocities. Although Ludvigh and Miller were careful to stress the empirical nature of their derivation and to disclaim a theoretical basis for this description of the DVA function, the general form of the equation has attained considerable acceptance among investigators, with only occasional deviation regarding the value of the exponent, n (8, 17, 24, 28).

While the above equation is generally descriptive of averaged DVA data for groups of subjects, individual subjects exhibit marked variabilities which are at variance with a fundamental characteristic of the equation. Taken as a model of the DVA function, this equation predicts that acuity will be degraded as a continuous, monotonic, positively accelerating function of target angular velocity. However, in the original data upon which the equation is based, ten of the fourteen subjects tested at 10°/sec produced higher mean thresholds at this speed than at 20°/sec (3). Cutler and Ley (35) reported a possible plateau, or brief reversal, occuring in the DVA function at target angular velocities between 20 and 50°/sec. S. I. Miller and Reeder (36) reported plateaus and reversals for velocities above 60°/sec when free head movement was allowed. Goodson and Miller (9) obtained data similar to those of Ludvigh and Miller when a single target was used, but when the same subjects were tested using two Landolt rings placed side by side, their DVA performance appeared to describe a linear, rather than cubic, function of target angular velocity.

PROBLEM

Reported variations in linearity, magnitude, and continuity of the DVA function are generally treated as anomalies in the data. There is not yet an adequate basis for disentangling the confounding effects of large individual differences, high within-subject variabilities, and variation in apparatus and experimental procedures. Clarification of the quantitative characteristics of the DVA function is required if measures of this function are to be applied to the assessment and prediction of individual capabilities for visual performance, and if the understanding of this function is to influence task design.

This is the first of a planned series of reports concerning the investigation of the stimulus determinants of visual acquisition performance required in the DVA task. The major proposition of the series is that acquisition cues may be manipulated independently of resolution cues in a manner which will degrade or enhance DVA performance. The objectivies are to identify the stimulus characteristics which will improve the psychometric properties of DVA tests, and to investigate the stimulus determinants of visual acquisition.

The purposes of the remainder of this report are 1) to report baseline data representing the range and individual differences in DVA performance as measured on the present apparatus, and 2) to report descriptive, exploratory data regarding the effects of contrast, luminance, and target surround upon DVA performance.

METHOD

APPARATUS

Subjects viewed Landolt ring targets monocularly through a plane, front surface mirror, 10.2 cm high and 25.4 cm wide, which rotated in a counterclockwise direction about a vertical axis along its midline. The mirror was driven by a variable speed motor to provide desired angular rates. Target exposure was controlled by a rectangular aperture in a flat white mask attached to the mirror. The aperture height was 2.54 cm. Its width was defined empirically to allow 400 msec exposure for each angular velocity. The distance from center of rotation of the mirror to the eye was 19.5 cm, and to the target was 590.1 cm. The eye to mirror to target angle was 105°. The plane of incidence was perpendicular to the axis of mirror rotation. With this geometry, the rate of image movement with respect to the eye ($\frac{d\omega}{dt}$) is 1.94 times the rate of mirror rotation ($\frac{d\theta}{dt}$) (37). Calculated values of image variables are provided in Appendix A.

Targets were presented against a seamless, white, cylindrical background screen of 590.1 cm radius, 75.3° azimuth, and 274 cm height. The center of the screen's curvature was coincident with the axis of rotation of the mirror. The geometry of the room limited the arc size of this screen. A supplementary, flat screen slightly overlapped the right edge of the cylindrical screen to extend the white background an additional 40° in azimuth. The near edge of the flat screen was 376 cm from the mirror. A circular hole of 19 cm diameter was cut in the cylindrical screen for target presentation. The center of the hole was 120 cm from the floor and 34.6° from the edge of the flat screen. A target holder and positioning device was located directly behind the aperture. With a target in position flush against the back surface of the screen, the aperture was filled.

Counterclockwise rotation of the mirror produced image movement from right to left. Under full screen illumination, the rotating mirror reflected a perceptually uniform surface over 116.3° visual angle, except for a faint vertical line at 41° and the target at 76.6° from the right edge.

Three sets of Landolt ring targets were produced on matte photographic print paper and mounted on disks of 20.3 cm diameter. The three sets differed only in target-to-background contrast. Their contrast ratios are –.91, –.67, and –.35. $C = (L_T - L_B)/L_B$, where L_T = target luminance and L_B = background (surround) luminance. Each set includes eighteen gap sizes, ranging from 0.65 to 20.38 minutes of arc at a viewing distance of 609.6 cm.

Three conditions of full screen illumination were employed, producing luminance levels of 150.7 cd/m² (44 ft.L), 17.8 cd/m² (5.2 ft.L), and 0.34 cd/m² (0.1 ft.L). The two higher luminance levels were attained by use of 750-watt tungsten lamps mounted in Berkey-Colortran broad flood luminaires. Intensities were adjusted by means of crossed polarizing sheets. The lower luminance condition was attained by use of a 25-watt tungsten lamp. In addition to the full screen illumination conditions, three configurations of circumscribed luminance surrounding the target were employed: a circular disk of light 30.5 cm diameter subtended 2°52′, a rectangle 30.5 cm wide and 61 cm high subtended 2°52′ by 5°43′, and a rectangle 122 cm wide and 61 cm high subtended 11°25′ by 5°43′. These surround areas were imaged on the screen by a Kodak projector so that the Landolt C's appeared at their center. Intensities were controlled by cross polarizing filters. Under these surround conditions, the only illumination on the remainder of the screen was due to stray light, and provided luminance less than 0.1 cd/m².

PROCEDURE

Prior to each experimental session, the mirror drive was set for the proper speed, and the appropriate mirror aperture was installed to control exposure time of the target at 400 msec. Within an experimental session, target velocity and luminance condition remained constant.

All observers viewed the target with their right eye, their left eye being occluded by an eye patch. Observers were seated, and their eye position was aligned with respect to the mirror and target by use of an adjustable head and chin rest. The experimenter was stationed behind the screen in order to manage the targets. For each target presentation, the experimenter selected the appropriate target, and placed in a position with the gap in one of eight orientations. Target orientation was determined from a partially random table. The observer made a forced choice verbal response corresponding to one of eight possible gap orientations. An up-and-down psychophysical method was employed in which the target size was increased after an incorrect response and decreased after a correct response. The gap size for which an incorrect response followed a correct response was used as an estimate of threshold.

EXPERIMENT I. Individual Differences

Burg (21) measured binocular static and dynamic visual acuities of 17,500 automobile drivers who ranged in age from 16 to 92 years. Free head movement was allowed during the DVA tests. His data indicate that the decline in visual acuity with advancing age is more pronounced with moving targets than with stationary targets, and that variability in performance is higher for DVA than for static acuity.

Miller and Ludvigh (1, 38) tested DVA for a group of 1000 naval aviation cadets, all of whom had demonstrated static visual acuity (Snellen) of 20/20 or better. With a target angular velocity of 20°/sec, the mean acuity for this relatively homogeneous group of subjects was 1.93 minutes of arc, and the standard deviation was 0.70. With a target angular velocity of 110°/sec,

the mean was 6.10 minutes of arc, and the standard deviation was 3.23. Further, Ludvigh and Miller (25) demonstrated that the relative performance among subjects at low target angular velocities may be reversed for higher target speeds. That is, one subject may perform far better than another at low target velocities and far worse at higher target velocities.

PURPOSE

The purposes of the present experiment are to assure that the experimental apparatus and procedures are sensitive to individual differences in DVA abilities, and to demonstrate the range of performance on DVA which might be expected among a group of student naval aviator subjects who are relatively homogeneous with respect to static visual acuity.

PROCEDURE

Ten subjects participated in this experiment. The subjects were male student naval aviators between the ages of 18 and 22 years. All subjects demonstrated uncorrected static visual acuity of 20/20 or better on the Armed Forces Vision Tester.

Twelve threshold measures were obtained, using the staircase method, for each of four target angular velocities. The angular velocities of 20, 50, 80, and 110°/sec were presented in ascending order. Trials leading to the first two thresholds for each target velocity were treated as practice trials. Exposure time was 400 msec for all conditions. The luminance of the surrounding screen was 150.7 cd/m² (44 ft.L). Target contrast was –0.91.

RESULTS

The means and standard deviations were calculated for each subject's performance at each target angular velocity. These are presented in Table I. The data of subjects 1 through 6 reasonably represent the range of magnitude and variations in performance for this sample. Graphs of means and 95 percent confidence intervals for these six subjects are presented in Figure 1.

The following observations are pertinent:

1. Although all subjects had demonstrated their static visual acuity to be 20/20 or better, there is considerable variability in their DVA for targets moving as slowly as 20°/sec, and in the rates at which performance changes as a function of increased target velocity.

2. The mean performance of seven of the ten subjects was better for targets moving at 50°/sec than at 20°/sec, and four of the ten scored slightly better at 80°/sec than at 50°/sec. It is possible that learning played a part in this result since target velocities were presented in an ascending order. However, it may be the case that DVA is not a monotonic function of target angular velocity.

3. The range of performance among subjects is quite similar to ranges reported by Ludvigh and Miller (3).

Table I

Means and Standard Deviations (in parenthesis) of DVA Thresholds (n = 10) for Each of Ten Subjects

Subject	Angular Velocity 20°/sec	50°/sec	80°/sec	110°/sec
PS	1.94 (.36)	2.51 (.38)	3.11 (.74)	9.70 (1.42)
RL	1.82 (.45)	1.21 (.15)	2.13 (.28)	10.55 (1.63)
JB	1.13 (.26)	0.69 (.09)	1.13 (.18)	3.69 (.41)
DS	2.21 (.42)	1.79 (.20)	2.65 (.36)	6.35 (1.08)
DLS	2.02 (.32)	1.37 (.26)	1.56 (.29)	1.98 (.23)
GS	1.71 (.22)	1.56 (.13)	1.44 (.37)	1.52 (.28)
TK	1.01 (.23)	0.85 (.21)	1.29 (.21)	1.90 (.76)
RD	1.33 (.19)	1.21 (.42)	0.77 (.19)	1.21 (.21)
JM	0.89 (.15)	1.40 (.33)	1.13 (.32)	1.56 (.29)
GG	0.81 (.15)	0.93 (.14)	1.29 (.20)	1.87 (.15)

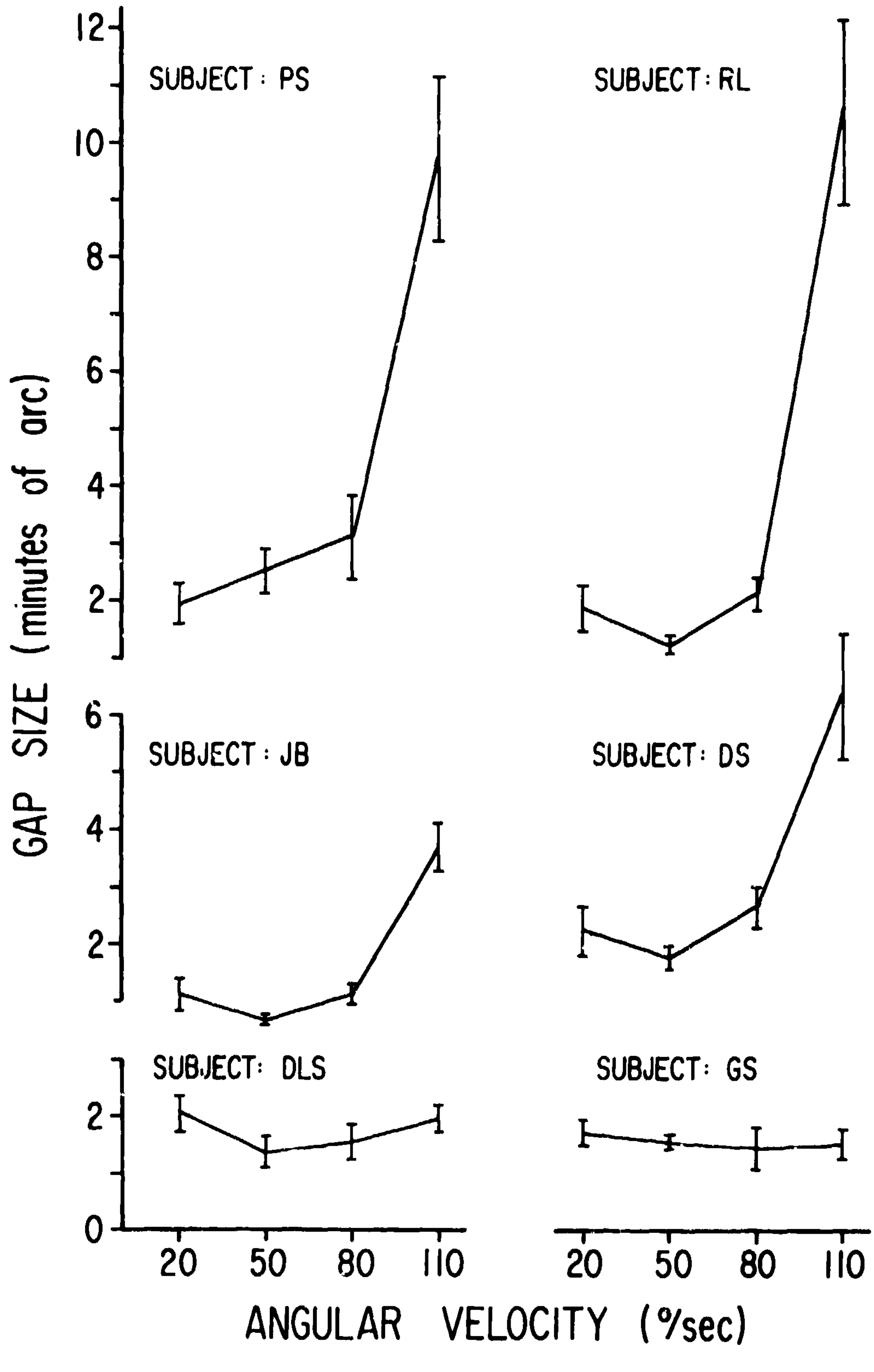

Figure 1. **Individual graphs of DVA for six subjects. Brackets indicate 95 percent confidence intervals** (*L* = *150.7 cd/m²*, *C* = *−0.91*).

EXPERIMENT 2. Contrast

The limiting visual function in DVA performance at lower target velocities appears to be related to static visual acuity, and the rates of degradation of DVA with increasing target velocities appear to depend upon the latency and accuracy of oculomotor responses to targets in motion. Static visual acuity, saccadic latency, and accuracy of ocular pursuit all appear to depend upon brightness contrast between the target and its background.

Ludvigh (39) demonstrated that static visual acuity performance decreases moderately when target contrast is reduced from 96.1 to 34.4 percent. Further reductions in contrast resulted in a rapid decline in static acuity. Ludvigh (7) proposed that the loss in DVA with increased target velocities may be due to a reduction in target contrast resulting from image motion on the retina when eye pursuit velocity does not match the angular velocity of the target.

Brown (19) recorded eye movements while measuring DVA performance under four conditions of target contrast ($C = +.70, +.51, +.36, +.23$; $L_B = 14$ cd/m²). His ANOVA design revealed significant main effects for contrast, target angular velocity, and subjects ($p < .001$ for each). There were indications in these data that latency of initial eye movements increased as target contrast was decreased, and that velocity error of the final smooth pursuit movement within a trial was increased for targets of lower contrast. Brown suggested that this result would appear more clearly using a target of constant size.

Haegerstrom-Portnoy and Brown (40) studied the effects of contrast upon eye movement responses to a disk subtending 5 minutes of arc which they moved at rates of 5, 15, 25, and 40°/sec. When target velocity and contrast were not predictable, eye tracking velocities increased (approached target velocities) with increasing target contrast over a narrow range of contrasts. Saccadic latencies decreased with increasing contrast for both predictable and unpredictable targets over a much larger range of contrasts. They also reported large individual differences in both saccadic and smooth pursuit responses.

PURPOSE

In Experiment 1, the DVA performance of several subjects was affected very little by target angular velocities up to 110°/sec, using high contrast targets. It might be expected that any special sensitivity of the DVA function to reduced contrast would be most easily demonstrated in the performance of subjects exhibiting such low variability both within velocity conditions and across target velocities. The purpose of the present experiment is to observe the effects of moderate reductions in target contrast upon the DVA of these high performers.

PROCEDURE

Three of the subjects in Experiment 1 (GS, JM, and GG) participated in this experiment. DVA was measured for each of the three subjects, using five target angular velocities (20, 50, 80, 110, and 124°/sec) and two levels of target contrast (–.67 and –.35). The order of conditions including the –.91 contrast condition from Experiment 1, is presented in Table II. Twelve thresholds were obtained under each condition. The first two of these were treated as practice, and not included in summary analyses.

RESULTS

Means and standard deviations were calculated for ten threshold measures obtained under each condition. These are presented in Table III. Means and 95 percent confidence intervals are presented graphically in Figure 2.

In general, the consistency and level of DVA performance exhibited by these subjects for high contrast targets were maintained for target contrasts of –.67 and –.35. However, the patterns of response over the conditions of this experiment appear to be dissimilar among subjects. Reference to Table II and Figure 2 will assist in evaluating the following comments. The guiding assumption in interpreting these data is that there is no reason to expect improved performance as a function of increased velocity or decreased contrast.

Given the above assumption, the apparent improvements in the performance of subject GS with increased target velocities and decreased contrasts appear to reflect the benefits of practice. However, continued improvement over this large number of trails would not be predicted from the work of Ludvigh and Miller (41–43), who observed performance to stabilize within the first twenty thresholds. The apparent improvement at 124°/sec may be due to a practice/recovery effect (last day) or to a plateau in the DVA function.

Subject JM's performance was the most consistent of the three, and appears to have not suffered importantly as a function of reduced contrast.

Subject GG performed significantly better for the high contrast condition ($C = -.91$) than for the low contrast condition ($C = -.35$) across target velocities. His responses under the intermediate contrast condition ($C = -.67$) were indistinguishable from those under high contrast condition at 20, 50, and 80°/sec, and shifted to become indistinguishable from those under low contrast at 110 and 124°/sec. Attention is called to the apparent plateau in this subject's performance at 124°/sec. Subsequent retesting at this velocity produced similar scores.

In Experiment 1, the low variabilities and high performance of Subjects GS, JM, and GG gave them the appearance of uniformity among a group exhibiting large individual differences. However, the data from the present experiment indicate considerable dissimilarities, even among these three subjects.

Table II

Order of Testing: Contrast

Subject	Day	Contrast	Angular Velocity
GS	1	−.91	20, 50, 80, 110°/sec
	4	−.35	20, 50, 80, 110°/sec
	5	−.67	20, 50, 80, 110°/sec
	7	−.91, −.35, −.67	124°/sec
JM	1	−.91	20, 50°/sec
	4	−.91	80, 110°/sec
	5	−.67	20, 50, 80, 110°/sec
	6	−.35	20, 50, 80, 110°/sec
	7	−.91, −.35, −.67	124°/sec
GG	1	−.91	20, 50, 80, 110, 124°/sec
	2	−.35	20, 50, 80, 110, 124°/sec
	5	−.67	20, 50, 80, 110, 124°/sec
	7	−.91, −.35	124°/sec (retest)

Table III

Effect of Contrast Upon DVA

Means and (Standard Deviations), n = 10.

		Angular Velocity				
Subject	Contrast	20°/sec	50°/sec	80°/sec	110°/sec	124°/sec
GS	−.91	1.71 (.22)	1.56 (.13)	1.44 (.37)	1.52 (.28)	1.29 (.15)
	−.67	1.05 (.30)	1.13 (.29)	1.11 (.57)	1.13 (.26)	0.89 (.20)
	−.35	1.01 (.28)	0.89 (.15)	2.12 (.41)	2.40 (.39)	1.33 (.23)
JM	−.91	0.89 (.15)	1.40 (.33)	1.13 (.32)	1.56 (.29)	1.48 (.21)
	−.67	0.81 (.20)	1.09 (.21)	1.32 (.32)	1.63 (.30)	1.98 (.29)
	−.35	1.09 (.31)	1.37 (.22)	1.71 (.23)	1.87 (.15)	2.35 (.23)
GG	−.91	0.81 (.15)	0.93 (.14)	1.29 (.20)	1.87 (.15)	1.60 (.27), 1.94 (.45)
	−.67	1.01 (.21)	0.89 (.15)	1.48 (.31)	2.70 (.52)	2.67 (.61)
	−.35	1.33 (.23)	1.82 (.32)	1.75 (.21)	2.73 (.35)	2.51 (.28), 2.31 (.46)

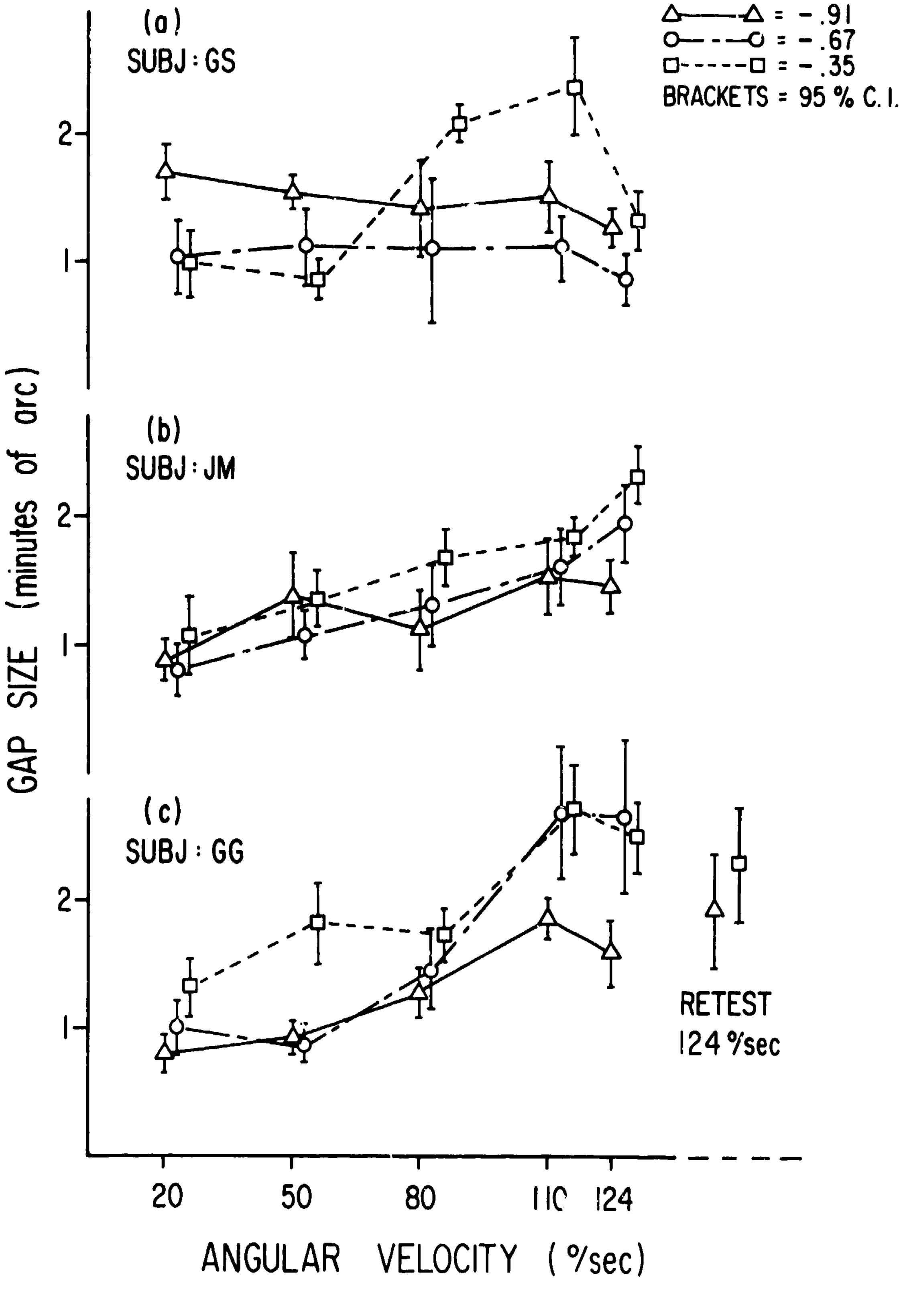

Figure 2. DVA for three levels of contrast, −0.91, −0.67, −0.35 ($C = \frac{L_T - L_B}{L_B}$, $L_B = 150.7\ cd/m^2$).

EXPERIMENT 3. Luminance, Contrast, and Surround

Differences among laboratories regarding the magnitude and linearity of the DVA function may be due, in part, to variations in the configuration and luminance of the stimulus field surrounding the acuity target, as well as to target contrast. The DVA literature includes variations in target and background luminance conditions ranging from a high positive contrast target in a dark field to a high negative contrast target against a bright field. Variations in surround configurations range from those incurred by viewing the target through microscope optics, to spotlight illumination of targets in a visual alley, to the presentation of targets against an extended white field. These sources of variability among laboratories, confounded with the large individual differences among subjects, leave little basis for identifying from the existing literature the characteristics of the visual processes and stimulus variables which are critical to the DVA function.

It is well known that visual acuity is affected by the intensity of light illuminating the acuity target. Hecht (44) recalculated and plotted the now classic data of Koenig (1897) to obtain a sigmoid curve representing visual acuity as a function of log luminance. The lower inflection point of this curve is associated with the transition from rod to cone vision, and the upper inflection point signals an approach to the limit of visual resolution. Between the two inflections visual acuity is approximately proportional to log luminance. Shlaer (45) demonstrated that the slopes and limits of this curve are dependent upon the choice of test target. Acuity for a Landolt C continues to improve with increasing luminance well above the luminance levels at which acuity for a grating target has stabilized. In either case, the benefits of increased luminance for static visual acuity appear to diminish rapidly as luminance levels exceed 34 cd/m^2.

Methling (46) measured the visual acuities of two subjects, using target velocities of 0, 40, and 70°/sec for one subject, and 0, 40, and 80°/sec for the other, at luminance levels ranging from 38 to 3200 cd/m^2. He concluded that the luminance functions for these target velocities were parallel, the optimum performance occurring at approximately 1000 cd/m^2 in each case. However, both Ludvigh (7) and Miller (6, 20) reported that acuity for moving targets continues to improve significantly with increased luminance above levels at which static acuity has essentially stabilized.

The effects of the variables which define the target surround have received little attention in the case of static visual acuity and none in the case of DVA. Lythgoe (47) measured static visual acuity with a small target area illuminated and then with the full field illuminated. His subjects viewed Landolt ring targets through a small aperture in a wall of the cubicle in which they were seated. Illumination of the walls of the cubicle provided the surround brightness.

He found that acuity improved with increases in surround brightness up to 10 percent of target brightness, followed by a slight depression at equal brightness, and a definite depression when the surround was brighter than the target area. Further, his subjects continued to improve with increasing target luminance up to 343 cd/m² when the surround was bright (130 cd/m²). When the surround was dark, he found a degradation in performance for target luminance above 43 cd/m².

Fisher (48) included five sizes of surround fields in a similar experiment. His subjects viewed an adjustable grating target through a 2 mm artificial pupil and a 2° aperture in the center of a "surround" disk. The five sizes of disks subtended 7, 12, 17, 27, and 42°. The target and surrounds were presented with combinations of the following luminance levels: 0.919, 0.064, 3.35, 104.8, and 2846 cd/m². Fisher concluded that 1) when surround luminance is less than that of the target, acuity improves with increasing surround size; 2) when surround luminance is higher than target luminance, acuity is degraded with increasing surround size; and 3) increasing the surround size when target and surround luminance are equal had no consistent effect.

These results are in reasonable agreement with those of Craik (49) in his investigation of the effects of adaptation upon visual acuity. He measured acuity for a parallel line target in a 16° circular field under combinations of adaptation and testing luminances ranging from 0.003 to 34,000 cd/m². He showed that for test luminances of 34 cd/m² and above, acuity was highest when the adapting and test luminances were equal. At lower test luminances the best acuity was obtained with prior adaptation to less bright fields.

Westheimer (50, 51) investigated the effects of the brightness and size of a stimulus surround upon the increment threshold for a small flashing spot in the center of the surround area. In the peripheral retina (10° temporal) he found that the scotopic increment threshold for a small, brief stimulus was progressively raised by increasing the size of a surround stimulus up to a size of 45 minutes of arc. Under conditions of partial light adaptation the continued growth of the surround stimulus lowered the increment threshold once more (50). Westheimer (51) observed a similar spatial interaction for cone vision. The critical surround size was 5 minutes of arc for the foveal area, and increased with distance from the fovea.

Variations in stable surround conditions which are shown to influence performance of static acuity and detection tasks are well within the range of variations in the visual environments used for DVA experiments. The requirement to pursue the moving DVA target adds a transient characteristic to the nature of the proximal stimulus for this task. Boynton and N. D. Miller (52) found that the contrast required for recognition of a briefly exposed letter presented 0.3 sec after a sudden change in the surround luminance increases as a function of the magnitude of the change. The range of luminances they used was 0.13 to 127 cd/m².

Wheeless et al. (53) showed that the latency of saccadic eye movements in response to positive contrast targets decreased as the target luminance was increased.

Initial information about the DVA target is obtained while the eye is reasonably stationary and the rate of movement of the target image over the retina is approximately equal to the target angular velocity. Although questions regarding the perception of movement of targets at minimum velocities have received considerable attention, studies which deal with upper velocity thresholds are few. Pollock (54) obtained luminance thresholds for the detection of a 1° light disk moving over a 20° arc in a dark field at velocities up to 2000°/sec. He found that the log luminance of the disk required for detection varies as a linear function of target velocity. Detection thresholds for vertical movement were slightly lower than those for horizontal movement, as is the case for recognition thresholds in DVA (5). A similar linear relationship for the detection of moving stimuli was reported by Brown (55, 56) and Johnstone and Riggs (57). In addition to detection thresholds, these authors determined thresholds for identifying the direction of stimulus movement. Brown (55, 56) moved a disk which subtended 1.8 minutes of arc along horizontal paths of 1.7, 5.2, 17, and 53 minutes of arc at velocities up to 51°/sec. He found that direction thresholds agreed approximately with detection thresholds at lower stimulus velocities but diverged upward as a limiting stimulus velocity between 30 and 40°/sec was approached. Johnstone and Riggs (57) moved a 12° by 3° luminous rectangle over a 6° path at rates varying from 80 to 640°/sec. The luminance thresholds for both detection and direction appeared to agree at 80°/sec and to diverge as two linear functions of velocity for velocities up to 640°/sec.

PURPOSE

Stimulus characteristics which are important to the resolution of stationary targets include not only the contrast and luminance at the target border, but also the extent over which the luminance applies. This is due apparently to the influence of adaptation and spatial interactions within the retina. Similar considerations must apply for the recognition of a DVA target, with added complications related to the dynamic responses required for detection and tracking of the moving target. Small surrounds or nearby borders may provide the salient cues for detection and tracking of a moving target. On the other hand, the brief exposure to a bright target surround within a dark field may degrade performance because of transient adaptation requirements. The purpose of the present experiment is to provide exploratory data regarding the effects of contrast, luminance, and configurations of surround luminance upon DVA performance.

PROCEDURE

Two male subjects between 20 and 26 years of age participated in this experiment. Subject DW demonstrated 20/20 static visual acuity without correction. Subject LF demonstrated 20/20 static acuity with correction, and wore corrective spectacles during the experiment.

The experiment employed three levels of target luminance (150.7, 17.8, 0.34 cd/m²), two contrasts (−.91, −.35), and four areal configurations of target surround (SA-1 through SA-4). The first surround area (SA-1) condition employed full screen illumination as described for Experiments 1 and 2. The remaining three surround areas were provided by projected images of a disk, or one of two rectangles, centered on the Landolt C target. SA-2 was a disk of 30.5 cm (1 ft) diameter which subtended 2°52′ visual angle. SA-3 was a rectangle 30.5 cm (1 ft) wide and 61.0 cm (2 ft) high which subtended 2°52′ by 5°43′. SA-4 was a rectangle 122.0 cm (4 ft) wide and 61.0 cm (2 ft) high which subtended 11°25′ by 5°43′ visual angle.

DVA thresholds were obtained for Subject LF under two luminance conditions (150.7 and 17.8 cd/m²), two contrast conditions (−.91, and −.35), and three surround conditions (SA-1, 2, and 4). Subject DW received the same two contrast conditions, all four surround conditions, and two luminance conditions (150.7 and 0.34 cd/m²). For each combination of conditions the DVA task was administered first with a target velocity of 20°/sec, then 124°/sec. If the subject did not respond correctly to the largest targets moving at 124°/sec, the velocity was reduced to 80°/sec. If thresholds were not obtainable at 80°/sec, the target velocity was reduced to 50°/sec. The order of conditions for each subject is presented in Table IV.

Five thresholds were obtained at 20°/sec for each condition. Ten thresholds were obtained at the higher target velocity, but only the last five were included in analyses.

RESULTS

Means and standard deviations were calculated for the last five thresholds obtained under each condition. These are presented in Table V. Means and 95 percent confidence intervals are presented graphically in Figures 3 and 4. Confidence intervals of magnitudes less than 0.5 are not plotted.

The most striking result of this experiment is the degradation in DVA performance associated with restrictions of the target's luminous surround. Performance appears to be most degraded by the smallest surround area for all luminance and contrast conditions.

Table IV

Order of Testing: Luminance, Contrast, Surround

Subject	Day	Luminance	Contrast	Surround	Angular Velocity
LF	1	150.7 cd/m^2	−.91	SA-3	20, 124°/sec
				SA-1	20, 124°/sec
				SA-4	20, 124°/sec
			−.35	SA-3	20, 124°/sec
				SA-1	20, 124°/sec
				SA-4	20, 124°/sec
	2	17.8 cd/m^2	−.91	SA-3	20, 124°/sec
				SA-1	20, 124°/sec
	3			SA-4	20, 124°/sec
			−.35	SA-3	20, 124°/sec
	4			SA-1	20, 124°/sec
				SA-4	20, 124°/sec
DW	1	150.7 cd/m^2	−.91	SA-4	20, 124°/sec
	2			SA-2	20, 124°/sec
	3			SA-3	20, 124°/sec
	4			SA-1	20, 124°/sec
			−.35	SA-4	20, 124°/sec
	5			SA-2	20, 124, 80°/sec
				SA-3	20, 124°/sec
	6			SA-1	20, 124°/sec
	7	0.34 cd/m^2	−.91	SA-4	20, 124°/sec
				SA-3	20, 124, 80°/sec
	8			SA-2	20, 124, 80°/sec
				SA-1	20, 124, 80°/sec
	9		−.35	SA-4	20, 80°/sec
				SA-3	20, 80, 50°/sec
	10			SA-2	20, 80, 50°/sec
	11			SA-1	20, 80°/sec

Table V

Effects of Luminance, Contrast and Surround Upon DVA

Means and (Standard Deviations), N = 5.

Subject	Luminance	Contrast	Surround	20°/sec	50°/sec	80°/sec	124°/sec
				Angular Velocity			
LF	150.7 cd/m²	−.91	SA-1	1.83 (.33)			5.32 (1.35)
			SA-3	2.05 (.25)			8.87 (3.43)
			SA-4	1.90 (.21)			5.32 (1.35)
		−.35	SA-1	2.35 (.43)			7.59 (2.34)
			SA-3	4.06 (1.01)			10.30 (1.87)
			SA-4	1.90 (.39)			7.01 (1.50)
	17.8 cd/m²	−.91	SA-1	2.36 (.79)			6.46 (1.19)
			SA-3	3.88 (.47)			5.92 (.90)
			SA-4	1.44 (.48)			4.29 (0)
		−.35	SA-1	1.98 (.72)			5.32 (1.35)
			SA-3	3.92 (1.02)			10.39 (3.07)
			SA-4	1.90 (.84)			7.00 (.94)
DW	150.7 cd/m²		SA-1	1.91 (.78)			3.78 (1.00)
			SA-2	5.89 (1.75)			9.31 (1.84)
			SA-3	3.90 (1.36)			7.03 (1.97)
			SA-4	3.61 (.58)			8.47 (2.66)
		−.35	SA-1	2.91 (.87)			4.29 (0)
			SA-2	6.93 (3.62)		14.00 (3.56)	
			SA-3	4.90 (2.25)			18.02 (1.17)
			SA-4	4.21 (1.04)			10.20 (1.64)
	0.34 cd/m²	−.91	SA-1	4.63 (.57)		7.01 (1.50)	14.76 (.39)
			SA-2	5.18 (1.58)		8.44 (2.06)	
			SA-3	4.18 (.79)		9.97 (3.41)	
			SA-4	3.49 (.66)		5.23 (.96)	16.66 (3.02)
		−.35	SA-1	7.01 (1.50)		12.67 (4.54)	
			SA-2	8.72 (1.64)	10.59 (1.76)		
			SA-3	6.76 (1.91)		15.36 ([illegible].48)	
			SA-4	4.31 (1.53)		10.89 (1.52)	

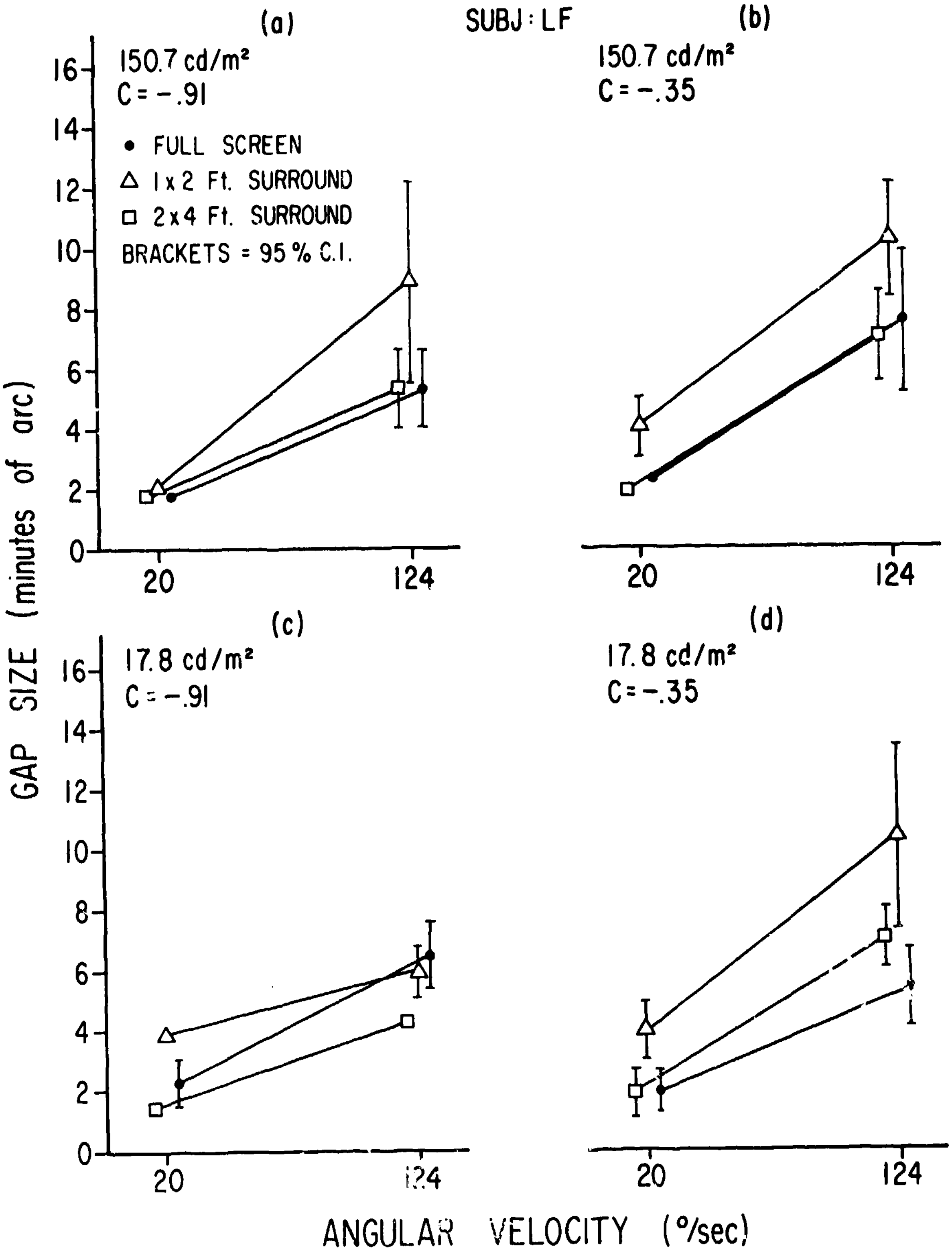

Figure 3. DVA of Subject LF for two levels of contrast (-0.91, -0.35), two levels of luminance (150.7, 17.8 cd/m²), and three target surrounds (• = full screen, △ = 2°52′ x 5°43′ rectangle, □ = 11°25′ x 5°43′ rectangle). Brackets indicate 95 percent confidence intervals. Confidence intervals <0.5 are not plotted.

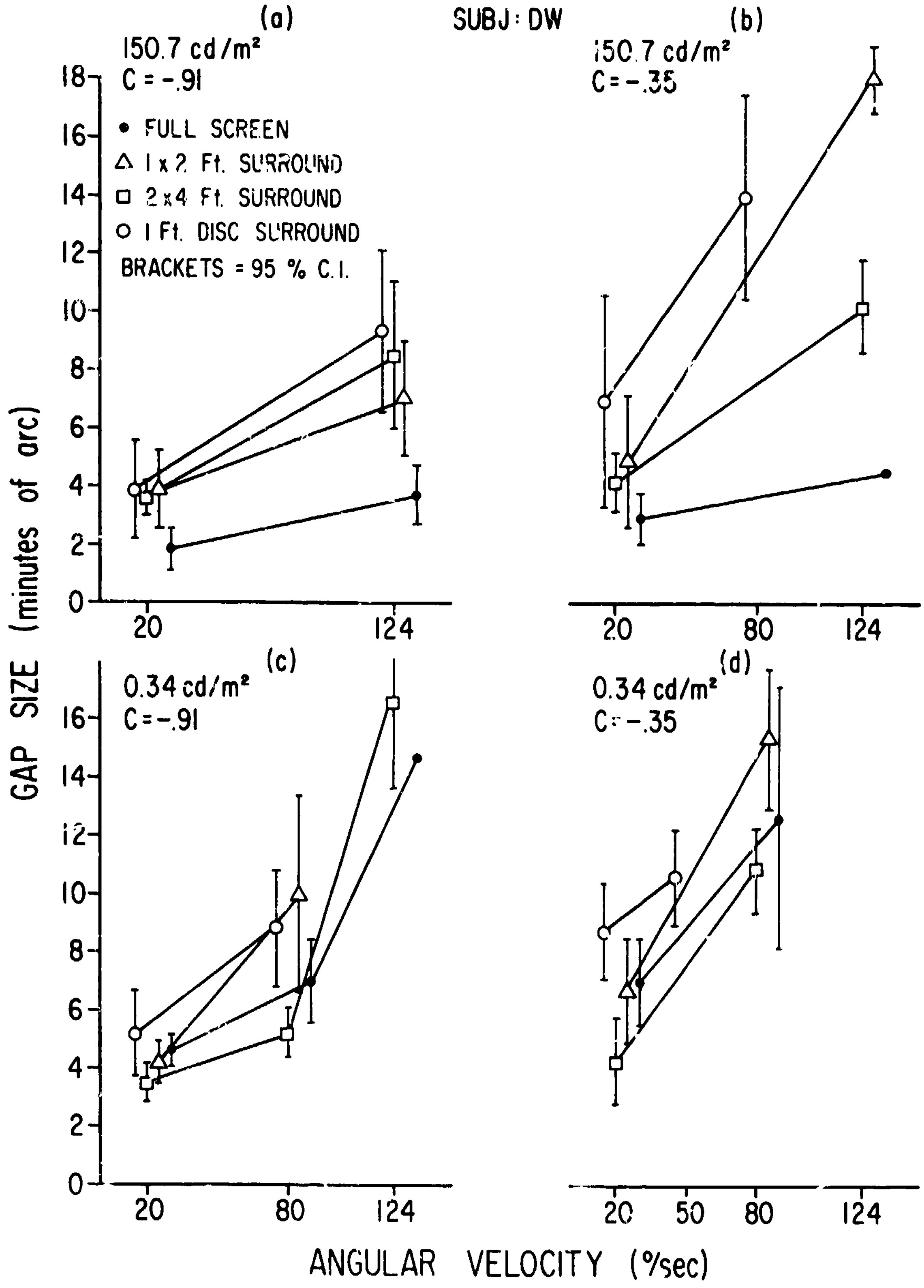

Figure 4. DVA of Subject DW for two levels of contrast (-0.91, -0.35), two levels of luminance (150.7, 0.34 cd/m²), and three target surrounds (• = full screen, △ = 2°52' x 5°43' rectangle, □ = 11°25' x 5°52' rectangle, ○ = 2°52' disc). Brackets indicate 95 percent confidence intervals. Confidence intervals <0.5 are not plotted.

Marked differences between the two subjects are apparent in their susceptibilities to changes in contrast and surround at the highest luminance level. Figures 3(a) and 3(b) indicate that Subject LF performed about equally well under the higher and lower contrast conditions for each surround condition. Whereas, Figures 4(a) and 4(b) indicate that the reduction in contrast resulted in severe degradation of Subject DW's performance for the two smaller target surrounds.

The reduction in luminance from 150.7 to 17.8 cd/m² appears to have had little effect upon Subject LF's performance. However, the reduction in luminance from 150.7 to 0.34 cd/m² severly affected the performance of Subject DW at higher target velocities for all contrast and surround conditions.

DISCUSSION

Standard tests of visual abilities generally are designed to optimize stimulus acquisition, and to avoid, rather than challenge, the dynamic oculomotor responses required for locating, scanning, or tracking visual stimuli. However, the performance of many practical visual tasks appears to be acquisition limited, depending critically upon coordinated visual and oculomotor abilities to search for and track visual targets and to scan visual displays. The measurement approach represented in DVA experiments appears to offer a methodology for assessing dynamic visual capabilities which are important in practical job performance, as well as a methodology for investigating important characteristics of these visual acquisition functions. However, this approach needs further refinement in order to realize its measurement potential.

There are large variations in DVA measures obtained among subjects, within subjects, and among laboratories. The ability to discriminate among subjects is a most important characteristic of a test. Any reduction in within-subject variability would enhance this valuable characteristic.

The major problem related to within-subject variability concerns the nature of changes in performance as a function of time and/or practice. Are these changes real or artifactual? If they are real, to what extent do they represent changes in task specific skill versus more general changes in the functional state of the subject? Ludvigh and Miller investigated the effects of practice upon DVA performance (41—43). Their data indicate that performance may improve with practice but stabilizes within the first 20 trials, that some subjects exhibit transfer of training from one target velocity to another, and that there are large individual differences in the amount of improvement exhibited among subjects. Even so, questions regarding apparent changes in DVA performance arise repeatedly in attempting to understand the studies reported in the literature as well as the present experiments.

An even more serious problem concerns the effects of differences among apparatus and procedures upon the level and variability of DVA performance. Although many of these differences are easily identified, the current state of knowledge does not provide an adequate basis for predicting the direction of their effects, let alone the magnitude. It is reasonable to expect that DVA is affected by the stimulus variables which affect static visual acuity, since both involve the resolution of visual detail. However, the manner in which these and other variables influence the dynamic interaction of visual and oculomotor responses required for DVA performance has not been determined. This area of inquiry is of utmost importance to the development and standardization of a reliable DVA test, to the quantitative definition of the DVA function, and to the understanding of the stimulus determinants of visual acquisition.

The data from the experiments reported here are of a descriptive and exploratory nature. Three conclusions appear to be supported by these data: 1) the levels and variabilities of measurements obtained in this laboratory are within the range expected on the basis of previous studies using similar methods, 2) the measured effects of changes in contrast and luminance upon DVA are consistent with existing data, and 3) the configuration of luminance surrounding the target has a large effect upon the DVA function. It is expected that unspecified variations in target surround provide an important source of variability in DVA measures among laboratories.

REFERENCES

1. Miller, J. W., and Ludvigh, E., The effect of relative motion on visual acuity. Surv. Ophthalmol., 7(2): 83-115, 1962.

2. Morrison, T. R., A review of dynamic visual acuity. NAMRL Monograph No. 28. Pensacola, Fl.: Naval Aerospace Medical Research Laboratory, March 1980.

3. Ludvigh, E., and Miller, J. W., A study of dynamic visual acuity. NSAM-562. Pensacola, Fl.: Naval School of Aviation Medicine, 1953.

4. Ludvigh, E., and Miller, J. W., Study of visual acuity during the ocular pursuit of moving test objects. I. Introduction. J. Opt. Soc. Am., 48(11): 799-802, 1958.

5. Miller, J. W. and Ludvigh, E., Dynamic visual acuity when the required pursuit movement of the eye is in a vertical plane. NSAM-563. Pensacola, Fl.: Naval School of Aviation Medicine, 1953.

6. Miller, J. W., Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination. J. Opt. Soc. Am., 48(11): 803-808, 1958.

7. Ludvigh, E. J., Visual acuity while one is viewing a moving object. Arch. Ophthalmol., 42: 14-22, 1949.

8. Miller, E. F., II, Ocular pursuit of a target moving in an apparent circular path. NSAM-517. Pensacola, Fl,: Naval School of Aviation Medicine, 1956.

9. Goodson, J. E., and Miller, J. W., Dynamic visual acuity in an applied setting. Aerospace Med., 30(10): 755-763, 1959.

10. DeKlerk, L. F. W., Eernest, J. Th., and Hoogerheide, J., The dynamic visual acuity of 30 selected pilots. Aeromed. Acta., 9: 129-136, 1964.

11. Burg, A., The relationship between vision test scores and driving record: General findings. Report No. 67-24. Los Angeles: University of California, Department of Engineering, June 1967.

12. Burg, A., Vision test scores and driving record: Additional findings. Report No. 68-27. Los Angeles: University of California, Department of Engineering, December 1968.

13. Henderson, R. L., and Burg, A., The role of vision and audition in truck and bus driving. TM-(L)-5260/000/00. Santa Monica, Ca.: Systems Development Corp., December 1973.

14. Elkin, E. H., Target velocity, exposure time and anticipatory tracking time as determinants of dynamic visual acuity (DVA). J. Eng. Psychol., 1: 26-33, 1962.

15. Miller, E. F., II, Effect of exposure time upon ability to perceive a moving target. NSAM-518. Pensacola, Fl.,: Naval School of Aviation Medicine, 1959.

16. Mackworth, N. H., and Kaplan, I. T., Visual acuity when the eyes are pursuing moving targets. Science, 136: 387-388, 1962.

17. Crawford, W. A., The perception of moving objects. I. Ability and visual acuity. Report FPRC/Memo 150a. Farnborough, England: Air Ministry Flying Personnel Research Committee, 1960.

18. Mayyasi, A. M., Beals, R. P., Templeton, A. E., and Hale, P. N., Jr., The effects of ambient illumination and contrast on dynamic visual acuity. Am. J. Optom. and Arch. Am. Acad. Optom., 48: 844-848, 1971.

19. Brown, B., The effect of target contrast variation on dynamic visual acuity and eye Movements. Vision Res., 12: 1213-1224, 1972.

20. Miller, J. W., The effect of altered illumination on visual acuity measured during ocular pursuit. NSAM-573. Pensacola, Fl.: Naval School of Aviation Medicine, 1956.

21. Burg, A., Visual acuity as measured by dynamic and static tests: A comparative evaluation. J. Appl. Psychol., 50(6): 460-466, 1966.

22. Burg, A., and Hulbert, S., Dynamic visual acuity as related to age, sex and static acuity. J. Appl. Psychol., 45(2): 111-116, 1961.

23. Weissman, S., and Freeburne, C. M., Relationship between static and dynamic visual acuity. J. Exp. Psychol., 70(2): 141-146, 1965.

24. Reading, V. M., Visual resolution as measured by dynamic and static tests. Pflügers Arch., 333: 17-26, 1972.

25. Ludvigh, E., and Miller, J. W., An analysis of dynamic visual acuity in a population of 200 naval aviation cadets. NSAM-568. Pensacola, Fl.: Naval School of Aviation Medicine, 1954.

26. Ludvigh, E., Visual and stereoscopic acuity for moving objects. Proceedings of Symposium on Physiological Psychology. ONR Report ACR-1. Washington, D. C.: Office of Naval Research, 125-136, 1955.

27. Ludvigh, E., Extrafoveal visual acuity as measured by Snellen test letters. Amer. J. Ophthalmol., 24: 303-310, 1941.

28. Brown, B., Dynamic visual acuity, eye movements and peripheral acuity for moving targets. Vision Res., 12: 305-321, 1972.

29. Barmack, N. H., Dynamic visual acuity as an index of eye movement control. Vision Res., 10: 1377-1391, 1970.

30. Reading, V. M., Analysis of eye movement responses and dynamic visual acuity. Pflügers Arch., 333: 27-34, 1972.

31. Crawford, W. A., The perception of moving objects. II. Eye movements. Report FPRC/Memo 150b. Farnborough, England: RAF Air Ministry Flying Personnel Research Committee, 1960.

32. Crawford, W. A., The perception of moving objects. IV. The accuracy of fixation required in the perception of detail in moving objects. Report FPRC/Memo 150d. Farnborough, England: RAF Air Ministry Flying Personnel Research Committee, 1960.

33. Westheimer, G., and McKee, S. P., Visual acuity in the presence of retinal-image motion. J. Opt. Soc. Am., 65: 847-850, 1975.

34. Murphy, B. J., Pattern thresholds for moving and stationary gratings during smooth eye movement. Vision Res., 18: 521-530, 1978.

35. Cutler, G. H., and Ley, A. H., Kinetic visual acuity. Br. J. Physiol. Opt., 20: 119-127, 1963.

36. Miller, S. I., and Reeder, C. E., Kinetic visual acuity. Br. J. Physiol. Opt., 22: 46-52, 1965.

37. Goodson, J. E., Dynamics of an image viewed through a rotating mirror. J. Opt. Soc. Am., 69: 771-775, 1979.

38. Miller, J. W., and Ludvigh, E., The results of testing the dynamic visual acuity of 1000 naval aviation cadets. NSAM-571. Pensacola, Fl: Naval School of Aviation Medicine, 1956.

39. Ludvigh, E., Effect of reduced contrast on visual acuity as measured by Snellen test letters. Arch. Ophthalmol., 25: 469-474, 1941.

40. Haegerstrom-Portnoy, G., and Brown, B., Contrast effects on smooth-pursuit eye movement velocity. Vision Res., 19: 169-174, 1979.

41. Ludvigh, E., and Miller, J. W., Some effects of training on dynamic visual acuity. NSAM-567. Pensacola, Fl: Naval School of Aviation Medicine, 1954.

42. Miller, J. W., and Ludvigh, E., An analysis of certain factors involved in the learning process of dynamic visual acuity for 1000 naval aviation cadets. NSAM-574. Pensacola, Fl.: Naval School of Aviation Medicine, 1957.

43. Ludvigh, E., and Miller, J. W., The effects on dynamic visual acuity of practice at one angular velocity on the subsequent performance at a second angular velocity. NSAM-570. Pensacola, Fl.: Naval School of Aviation Medicine, 1955.

44. Hecht, S., A quantitative basis for the relation between visual acuity and illumination. Proc. Natl. Acad. Sci., 13: 569-574, 1927.

45. Shlaer, S., The relation between visual acuity and illumination. J. Gen. Physiol., 21: 165-188, 1937.

46. Methling, D., Sehscharfe bei augenfolgebewegungen in abhangigkeit von der gesichtsfeldlencht-dichte. Vision Res., 10: 535-541, 1970.

47. Lythgoe, R. J., The measurement of visual acuity. Series 173 Report of the Committee upon the Physiology of Vision, Privy Council Medical Research Council, HM Stationary Office, 1932.

48. Fisher, M. B., The relationship of the size of the surrounding field to visual acuity in the fovea. J. Exp. Psychol., 23: 215-238, 1938.

49. Craik, K. J. W., The effect of adaptation upon visual acuity. Br. J. Psychol., 29: 252-266, 1939.

50. Westheimer, G., Spatial interaction in the human retina during scotopic vision. J. Physiol., 181: 881-894, 1965.

51. Westheimer, G., Spatial interaction in human cone vision. J. Physiol., 190: 139-154, 1967.

52. Boynton, R. M., and Miller, N. D., Visual performance under conditions of transient adaptation. Illum. Eng., 58: 541-550, 1963.

53. Wheeless, L. L., Jr., Cohen, G. H., and Boynton, R. M., Luminance as a parameter of the eye-movement control system. J. Opt. Soc. Am., 57(3): 394-400, 1967.

54. Pollock, W. T., The visibility of a target as a function of its speed of movement. J. Exp. Psychol., 45: 449-454, 1953.

55. Brown, R. H., The effect of extent on the intensity-time relation for the visual discrimination of movement. J. Comp. Physiol. Psychol., 50: 109-114, 1957.

56. Brown, R. H., Influence of stimulus luminance upon the upper speed threshold for the visual discrimination of movement. J. Opt. Soc. Am., 48: 125-128, 1958.

57. Johnstone, J. R., and Riggs, L. A., Upper-velocity threshold for detection of movement. Optics Letters, 4: 309-310, 1979.

APPENDIX A

Calculated Values of Image Variables as Functions of Mirror Position in the DVA Laboratory

APPENDIX A

Calculated Values of Image Variables as Functions of Mirror Position in the DVA Laboratory. (Parameters: Eye to Mirror distance = 19.5 cm, Mirror to Target distance = 590.1 cm, Included Angle = 105°)

Mirror Position* $\theta°$	Image Position* $\omega°$	$\frac{d\omega}{d\theta}$	$\frac{d^2\omega}{d\theta^2}$	Image Distance (cm)	Image Height (°)	Image Width (°)
115	65.777	1.941	-0.050	607.829	0.100	0.100
120	75.475	1.938	-0.030	608.956	0.100	0.100
125	85.160	1.936	-0.010	609.528	0.100	0.100
130	94.840	1.936	0.010	609.528	0.100	0.100
135	104.525	1.938	0.030	608.956	0.100	0.100

*Image position with respect to the eye is 90° when aligned with axis of mirror rotation. Mirror position is 90° when aligned with image position at 90°. Angular position of mirror and image increases with counterclockwise movement.